COFRDA REPORT 3315

Workday Probabilities for Aerial Herbicide Application in the Kapuskasing District of Northern Ontario

Forest Resource Development Agreement
Entente sur la mise en valeur de la ressource forestière

Canada

Ontario

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Les projets sont approuvés par un comité de gestion composé de représentants du Forêts Canada et du ministère des Richesses naturelles.

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Workday Probabilities for Aerial Herbicide Application in the Kapuskasing District of Northern Ontario

R.W. Arnup
Ecological Services for Planning, Ltd.
Timmins, Ontario

1991

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ABSTRACT

Aerial application of herbicides for tending of forest crops needs to be carried out under appropriate climatic conditions in order to be effective. These conditions vary diurnally as well as over the course of the tending season. Work probabilities, or estimates of the number of hours suitable for aerial herbicide application during specific intervals of time, can be developed from long-term climatic records. Timber management planning will benefit from information on the amount of time available for carrying out such field operations.

To provide an example, records obtained from the Atmospheric Environment Service for climatic monitoring stations at Kapuskasing were used to determine the daily and seasonal distribution of elements that affect aerial herbicide application, including wind speed, temperature, relative humidity and rainfall. Hourly climatic records were used to develop mean work probabilities on a weekly basis for Kapuskasing District over the summer tending season. The results are expected to be useful to government and industry foresters for the planning of tending operations in the Kapuskasing area.

RÉSUMÉ

L'épandage aérien d'herbicides comme méthode de soins culturaux des peuplements forestiers doit être fait dans des conditions climatiques appropriées pour être efficace. Ces conditions varient selon le moment de la journée et au cours de la saison d'entretien. Des probabilités de travail, ou des estimations du nombre d'heures approprié pour l'épandage aérien d'herbicides durant des intervalles de temps précis, peuvent être obtenues à partir des relevés climatiques à long terme. Les données sur le temps disponibles pour effectuer ces opérations sur le terrain permettront d'améliorer la planification de l'aménagement forestier.

Par exemple, les relevés obtenus auprès du Service de l'environnement atmosphérique pour les stations de surveillance climatique à Kapuskasing

ont permis de déterminer la distribution journalière et saisonnière des éléments qui influent sur l'épandage aérien d'herbicides, y compris la vitesse du vent, la température, l'humidité relative et les précipitations. Des relevés climatiques horaires ont été utilisés pour établir des probabilités de travail moyennes hebdomadaires pour le district de Kapuskasing, durant la saison estivale de soins culturaux. Les forestiers du gouvernement et de l'industrie pourront se servir de ces résultats pour planifier les opérations de soins culturaux dans la région de Kapuskasing.

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WORKDAY PROBABILITIES FOR AERIAL HERBICIDE APPLICATION IN THE KAPUSKASING DISTRICT OF NORTHERN ONTARIO

INTRODUCTION

In the forest sector, herbicides are used to increase early crop survival and to maximize growth and yield of plantations and natural stands of desirable species (mainly conifers) through the control of competing vegetation. Herbicides are not used to completely eradicate competition, but to reduce competition with desirable crop trees for light, nutrients and soil moisture. There are two main uses of herbicides in forestry — tending and site preparation. Chemical site preparation with herbicides is used to control unwanted vegetation before establishing the new crop, whereas tending refers to the treatment of existing young plantations to promote crop establishment and growth, or the release of natural stands of desirable trees from competing vegetation.

Tending is generally recognized as an essential part of forest management in northern Ontario. Aerial application of herbicides is the most common form of tending used in Ontario. For example, 64,071 ha of land were treated with herbicides for tending purposes in 1988 (Anon. 1988). In contrast, chemical site preparation represents only a small part of all site-preparation activities in Ontario.

The ability to predict the amount of time available for carrying out field operations in any given year would help to ensure effective planning for operational tending and site-preparation programs in forestry. This information may also be useful in conjunction with the computerized decision-support and economic models that are being developed for forest management in northern Ontario at the present time (e.g., Hynard 1984) by helping to determine the feasibility of implementing different management scenarios.

The usefulness of planning tools developed from long-term climatic records has been demonstrated by the agricultural community in Ontario. In both southern and northern Ontario, studies of workday probabilities and risk analyses based on long-term climatic information have been completed (e.g., Coligado et al. 1969, Brown 1976) and have served as decision-making tools for agricultural land-use planning. For example, knowledge of the risk of drought over the course of the growing season helps in planning irrigation needs.

The aerial application of herbicides needs to be carried out under specific and appropriate climatic conditions in order to be biologically effective. These conditions vary diurnally as well as over the course of the season and from year to year. Long-term records can be used to determine the daily and seasonal distribution of such climatic parameters as wind speed, temperature, relative humidity and rainfall.

As an example of a potential application, long-term hourly climatic records from the Atmospheric Environment Service Monitoring Station located at the Kapuskasing Airport were used to develop mean work probabilities on a daily and a weekly basis for the Kapuskasing District of northern Ontario. In this report, work probabilities refer to estimates of the number of hours that will be suitable for aerial herbicide application during specific intervals of time. Variability in the data was also examined to help estimate risk. To estimate geographic variations in climate within the District, data from fire-weather monitoring stations maintained by the Ontario Ministry of Natural Resources (OMNR) at several locations were also examined. The results are presented in a series of tables and figures, in a form suitable for use by those engaged in planning timber management operations.

METHODS

Climatic Requirements for Aerial Application of 2,4-D and Glyphosate

According to the label instructions for 2,4-D and Vision® (glyphosate), there are four climatic conditions that should be present to ensure that herbicide applications are both safe and effective (Anon. 1985a,1986, 1989). These are as follows:

1. For aerial application, wind speed must be less than 8 km/hr. In general, if spraying is being conducted near environmentally sensitive areas, even this low wind speed may be excessive unless the wind is blowing into the spray block away from the sensitive area.

2. Ambient air temperature should be less than 21°C, and greater than 5°C. This restriction is based on experience with 2,4-D but not Vision®. Air-temperature limits for aerial application of Vision® have not been quantified, but are assumed to be the same as for 2,4-D.

3. Relative humidity should be greater than 60% for 2,4-D applications. Relative humidity requirements for Vision® have not been established. In the interim, it was assumed that the same restriction as for 2,4-D applications will apply.

4. Rainfall within 30 min. to 2 hours after 2,4-D application or within 6 hours after Vision® application may reduce the effectiveness of the herbicides.

This last restriction is intended more for agricultural uses, in which the target species are some of the small grasses. In forestry, there is a greater area of interception as a result of the large canopy area, and this restriction is probably not required. As well, the application rate plays an important role in determining the effect of rainfall on the effectiveness of the application.[1]

For the purpose of compiling probabilities, rainfall exceeding 3 mm in one day was assumed to be limiting to aerial herbicide application.

In summary, the four climatic requirements for the aerial application of the herbicides 2,4-D and Vision® that were used as the criteria to calculate work probabilities are as follows:

1. Wind speeds no higher than 8 km/hr
2. Ambient air temperatures from 5° to 21°C inclusive
3. Relative humidity 60% or greater
4. Total rainfall less than 3 mm on the day of application

Data

Hourly data for wind speed, air temperature, relative humidity and precipitation were obtained from the Atmospheric Environment Service's Monitoring Station at the Kapuskasing Airport. For each year, hourly data were used for the period from 1 May to 30 September, inclusive. Wind speed, air temperature and relative humidity data were available for the period from 1953 to 1987 (35 years). Hourly precipitation data were available for the period from 1968 to 1987 (20 years). Hourly precipitation data were not recorded before 1968.

Data recorded at four fire-weather monitoring stations located in Opasatika, Harmon, Slack and Barker Townships in Kapuskasing District (Fig. 1) were obtained from the Ontario Ministry of Natural Resources for the year 1988. Long-term data for these stations is not available since the stations have changed locations from year to year. According to OMNR criteria, fire-weather monitoring stations are established on sites that are representative of the overall terrain of the area in which they are located. The data recorded at the fire-weather stations includes wind speed, air temperature, relative humidity and total precipitation, recorded at 0800 and 1300 hours daily, from approximately mid-May through mid-September. For direct comparison with these data, similar information was obtained

[1]Monsanto Canada Inc. Mississauga, Ont. 1989. Personal communication.

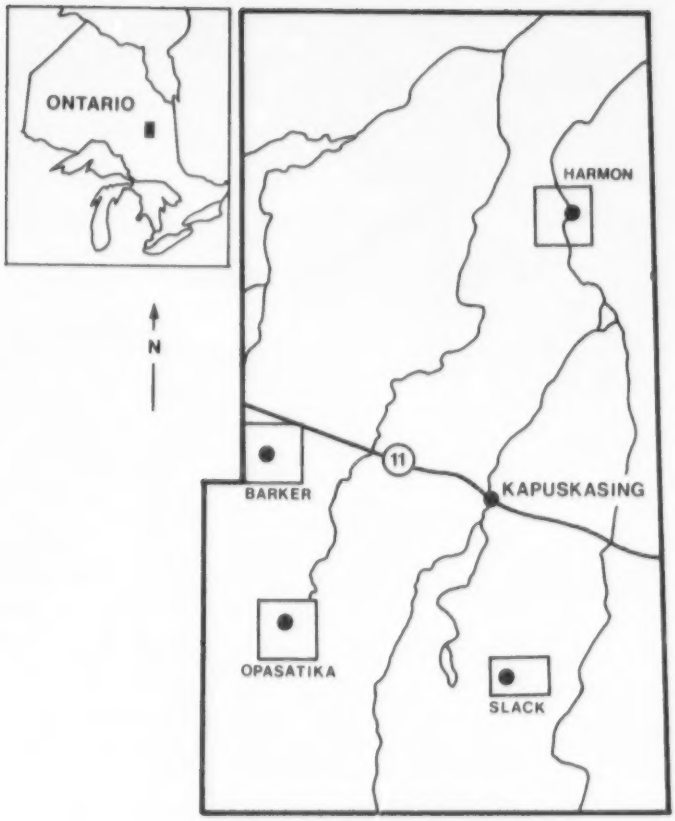

Figure 1. Aproximate locations of four OMNR fire-weather monitoring stations and of the Environment Canada monitoring station in Kapuskasing District.

from the Atmospheric Environment Service Monitoring Station at the Canada Department of Agriculture Experimental Farm near Kapuskasing. Since the experimental farm is located adjacent to the Kapuskasing Airport, the data from the two sources are comparable.

Analyses

For each hourly record in the database, the four criteria listed in the section on climatic requirements were compared with the actual weather conditions to determine whether suitable conditions for herbicide application were present. If the values for all four climatic parameters were within acceptable limits, then that hour was considered to have been suitable for aerial herbicide application. The total number of suitable hours was then summed on a weekly basis. These weekly sums were then divided by the total potential number of hours available in each week to generate weekly estimates of the proportion of suitable hours compared with total hours available. Weekly point estimates for each year were then averaged over 20 years to provide long-term estimates of the total number of suitable hours, and the percentage of suitable hours compared with the total number of hours available (i.e., work probabilities). In this way, weekly work probability tables based on each individual climatic attribute (wind speed, air temperature, relative humidity and precipitation) were prepared to allow an examination of the relative contribution of each attribute to the overall work chance. Overall work probabilities based on all four climatic parameters were also prepared. The variability to be expected for the total number of available work hours and the long-term variability for each climatic attribute were also examined and summarized.

Data from the fire-weather monitoring stations were compared with corresponding data from the Kapuskasing Experimental Farm to determine if significant differences were present, using paired-sample t-tests. Since weather conditions at 1300 hours are rarely suitable for aerial spraying, comparisons were confined to observed spray conditions at 0800 hours. The total number of suitable work hours were summarized for each station to give a point estimate of geographic variability within the District; these estimates were used to help estimate the potential effect of geographic variability in climate on the work times available.

RESULTS AND DISCUSSION

Work Probabilities

The 35-year mean percentages of time that hourly wind speed values were greater than 8 km/hr represent the chance that wind speeds too high for aerial herbicide applications will occur during these time periods. These probabilities are listed in Table 1 for the hours 0500 to 2200, on a week-by-week basis from 1 May to 25 September. Table 2 shows mean weekly temperatures from 0500 to 2200. Highlighted portions of the table represent times when the mean air temperatures would be outside the limits required for effective aerial spray application, i.e., between 5° and 21°C.

Mean weekly relative humidity values for the hours 0500 to 2200 are listed in Table 3. Highlighted areas of this table show times when the mean relative humidity is less than the required minimum of 60%. The mean weekly probabilities that precipitation values will be greater than 3 mm are listed in Table 4 for the hours from 0500 to 2200 and for total daily precipitation. These probabilities represent the chance that rainfall exceeding 3 mm will occur during these time periods; hence, they represent the chance of unsuitable herbicide application weather.

Although the mean wind speed, air temperature and relative humidity values show clear daily patterns that vary over the course of a season in a predictable fashion, rainfall is less predictable, though some general patterns can be observed from Table 4. In general, the chance of rain increases as the season progresses, and the chance of rain is greater later in the day (after about 1400 hours). Note that mean rainfall and wind speed values are lower during the week of August 21 than at almost any other time. The reason for this apparent anomaly is not known.

Mean and standard deviation values for wind speed, air temperature, relative humidity and precipitation are listed on a weekly basis for the hours 0500 to 2200 in Tables 5 through 8. Standard deviation values for relative humidity and air temperature during the spray windows typically range from 20 to 30% of the mean values. The mean wind speeds are rarely less than the minimum required for aerial spraying (8 km/hr). Wind speed is more variable than relative humidity and air temperature, with standard deviation values ranging from approximately 60 to 80% of the mean values. Mean values for precipitation range from 0.2 to 3.2 mm. Standard deviation values for precipitation exceed the mean values in all cases.

Planning is mainly concerned with forecasting or predicting future events. The variability of such events indicates the degree of predictability for these variables. Therefore, there is a considerable element of risk involved in trying to predict wind speed and rainfall. Predictions based on relative humidity and air temperature are more reliable.

When wind speed, air temperature, relative humidity and rainfall parameters are all within acceptable limits, conditions for aerial herbicide applications are ideal. Overall work probabilities take into account the criteria for all four climatic parameters in any given period of time. Mean hourly work probabilities are summarized in Table 9 on a weekly basis for the period from 1 May to 30 September. Numbers in the table that have been doubly underlined show times when the probabilities of encountering ideal weather conditions exceed 40%; singly underlined numbers show times when the probabilities exceed 10%.

In general, the overall probabilities are less than 20% from 1000 hours (10:00 a.m.) to 1800 hours (6:00 p.m.) throughout the year. Using 40% work chance as an arbitrary criterion, two "windows" most likely to be suitable for spray applications can be identified for Kapuskasing, one for the morning hours and one for the evening. The length of time available in the morning window increases from May through July and then decreases from August through

Table 1. Weekly percent probabilities that wind speeds will exceed 8 km/hr from 0500 to 2200 hours, based on 35-year (1953-1987) hourly records from the Kapuskasing airport.

	Time of day (hours)																	
Week starting	0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200
May 01	64	66	68	76	78	84	86	86	85	89	91	89	90	88	80	71	68	67
May 08	65	66	74	80	80	81	84	86	88	89	85	87	87	87	85	75	69	68
May 15	63	65	73	75	80	84	85	86	88	91	90	89	90	84	86	70	66	66
May 22	53	58	67	73	73	72	80	82	82	84	83	84	83	82	79	63	65	62
May 29	55	59	67	70	77	78	81	85	87	88	84	82	87	74	73	62	59	62
June 05	60	64	71	78	79	82	80	84	86	82	82	84	78	81	79	64	64	64
June 12	50	54	62	68	73	77	78	80	79	83	81	81	80	80	74	55	55	56
June 19	51	57	63	68	72	78	83	85	87	85	87	84	82	78	71	58	57	55
June 26	58	58	62	72	75	78	80	82	84	84	83	79	79	77	69	58	56	57
July 03	54	58	61	70	74	81	81	82	84	83	83	80	82	72	70	56	52	57
July 10	46	53	60	62	71	76	78	82	83	82	76	78	74	73	64	49	48	52
July 17	43	46	54	60	67	73	76	78	77	79	78	76	76	71	63	50	46	47
July 24	53	57	63	65	71	76	82	82	85	83	82	79	76	71	63	51	51	55
July 31	46	44	51	66	70	78	78	80	81	80	79	73	75	62	52	45	47	49
August 07	50	53	58	67	71	75	79	80	79	81	84	81	74	67	64	56	56	54
August 14	60	57	60	71	74	77	81	82	83	84	84	81	77	69	58	50	49	53
August 21	51	53	53	63	65	73	76	79	78	80	80	79	72	64	56	52	56	53
August 28	54	55	62	67	69	78	79	83	82	82	78	78	71	65	5[illegible]	52	59	61
September 04	62	60	63	72	78	78	83	89	85	88	88	87	83	72	67	64	61	61
September 11	53	55	57	73	75	83	85	84	84	86	87	85	81	69	60	56	56	53
September 18	59	62	62	72	77	79	84	85	87	86	85	84	80	70	61	63	69	64
September 25	65	62	63	65	72	78	81	84	85	87	83	83	80	66	60	60	61	61

Table 2. Weekly mean ambient air temperatures (°C) for Kapuskasing from 0500 to 2200 hours, based on 35-year (1953-1987) hourly records from the Kapuskasing airport.

Week starting	Time of day (hours)																	
	0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200
May 01	0.1	0.4	1.4	3.4	4.9	6.3	7.4	8.3	9.1	9.9	10.3	10.4	10.2	9.7	9.0	7.2	5.7	4.5
May 08	1.7	2.1	3.1	5.0	6.4	7.6	8.7	9.6	10.3	11.0	11.4	11.5	11.3	10.8	10.1	8.5	7.1	6.1
May 15	4.0	4.5	5.7	7.6	9.1	10.5	11.6	12.6	13.4	14.1	14.4	14.5	14.3	13.8	13.1	11.3	9.7	8.5
May 22	5.5	6.2	7.5	9.5	11.1	12.4	13.5	14.5	15.1	16.0	16.4	16.5	16.3	15.9	15.3	13.5	11.8	10.5
May 29	5.9	6.7	8.1	10.0	11.6	12.8	13.9	14.9	15.5	16.0	16.3	16.6	16.5	16.1	15.6	14.1	12.3	10.9
June 05	7.7	8.4	9.5	11.4	12.9	14.1	15.2	16.1	16.7	17.4	17.6	17.7	17.7	17.2	16.5	14.9	13.2	12.0
June 12	8.8	9.8	11.0	12.9	14.4	15.8	16.9	17.8	18.3	19.0	19.2	19.4	19.3	18.9	18.3	16.7	14.7	13.5
June 19	9.4	10.3	11.6	13.5	15.0	16.4	17.5	18.3	19.0	19.6	19.8	19.9	19.8	19.4	18.7	17.1	15.2	13.8
June 26	11.4	12.2	13.4	15.1	16.6	17.9	19.0	19.9	20.5	21.4	21.7	21.8	21.4	20.8	20.2	18.3	16.5	15.3
July 03	11.1	11.9	13.1	15.2	16.9	18.2	19.3	20.2	20.6	21.2	21.4	21.5	21.4	20.9	20.2	18.5	16.6	15.4
July 10	11.6	12.3	13.6	15.6	17.2	18.6	19.7	20.6	21.3	21.9	22.2	22.2	22.1	21.5	20.8	19.0	17.2	16.0
July 17	12.3	12.9	14.3	16.3	17.9	19.2	20.2	21.0	21.5	22.1	22.6	22.6	22.4	21.9	21.2	19.2	17.4	16.3
July 24	12.0	12.5	13.5	15.4	17.0	18.3	19.4	20.3	20.9	21.5	21.8	21.8	21.5	21.1	20.3	18.4	16.8	15.7
July 31	11.1	11.5	12.7	14.8	16.6	18.1	19.3	20.2	20.6	21.2	21.4	21.5	21.3	20.8	20.0	17.7	16.1	15.1
August 07	11.0	11.1	12.0	14.1	15.7	17.1	18.2	19.1	19.7	20.4	20.6	20.6	20.4	19.7	18.9	16.7	15.3	14.5
August 14	10.9	10.9	11.7	13.5	15.3	16.9	18.1	19.0	19.6	20.2	20.5	20.5	20.2	19.6	18.6	16.3	15.0	14.1
August 21	10.0	9.9	10.5	12.5	14.2	15.9	17.1	18.1	18.7	19.3	19.5	19.4	19.1	18.3	17.2	14.9	13.9	13.2
August 28	10.1	9.9	10.4	12.2	13.9	15.5	16.6	17.6	18.3	19.0	19.2	19.1	18.8	17.9	16.6	14.7	13.7	13.0
September 04	8.9	8.7	9.0	10.5	11.9	13.2	14.2	15.0	15.4	16.1	16.3	16.2	15.9	15.1	13.9	12.3	11.6	11.0
September 11	5.8	5.6	5.8	7.1	8.6	10.0	11.1	12.0	12.6	13.1	13.5	13.4	13.0	12.0	10.6	9.4	8.6	8.1
September 18	6.2	6.0	6.1	7.2	8.4	9.6	10.7	11.6	12.2	12.7	12.8	12.8	12.3	11.3	10.1	8.9	8.3	7.8
September 25	4.5	4.4	4.3	5.3	6.5	7.7	8.7	9.5	10.0	10.5	10.7	10.7	10.3	9.3	8.2	7.2	6.6	6.2

Underlined numbers show times when mean ambient air temperatures are less than 5 or greater than 21°C.

Table 3. Weekly mean relative humidity values (%) for Kapuskasing from 0500 to 2200 hours, based on 35-year (1953-1987) hourly records from the Kapuskasing airport.

Week starting	Time of day (hour)																	
	0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200
May 01	79	79	76	69	64	60	56	54	51	49	48	48	48	50	51	57	62	66
May 08	81	81	78	70	66	63	59	56	54	52	52	51	52	54	56	61	65	69
May 15	82	81	78	71	65	61	58	55	52	51	50	50	50	52	55	60	65	70
May 22	83	81	77	69	64	59	56	53	52	49	49	49	49	51	53	58	64	69
May 29	85	84	79	72	67	63	60	57	54	54	53	52	53	54	56	62	67	72
June 05	85	84	79	73	67	63	60	57	55	54	54	54	54	55	58	64	70	74
June 12	87	85	81	74	68	63	60	56	55	53	53	53	53	54	57	63	70	74
June 19	87	85	81	74	68	64	60	57	55	53	53	52	53	55	58	65	72	76
June 26	87	85	81	76	71	67	63	60	58	55	54	54	55	57	60	68	75	78
July 03	88	86	83	76	70	64	61	58	56	55	54	54	55	57	60	67	74	78
July 10	91	89	85	78	72	66	63	59	57	55	55	55	57	59	62	70	76	80
July 17	90	89	85	78	72	67	64	61	60	57	56	56	58	60	63	72	78	81
July 24	90	90	87	81	74	69	64	61	59	57	57	56	58	60	64	72	79	82
July 31	91	90	87	81	75	68	64	61	59	57	56	56	57	60	64	74	80	82
August 07	91	91	89	83	77	71	67	63	60	59	58	58	59	63	67	76	80	82
August 14	90	91	89	83	77	70	65	62	60	58	57	57	59	62	67	77	81	83
August 21	91	92	90	85	79	72	67	63	60	58	57	58	60	64	71	80	82	84
August 28	91	91	91	86	80	73	68	64	62	60	59	60	61	65	72	80	83	84
September 04	91	92	91	87	82	76	72	69	66	64	64	64	65	69	75	81	84	85
September 11	92	92	92	88	84	77	72	68	65	63	62	62	64	70	76	81	84	85
September 18	92	92	92	89	84	79	75	71	68	66	66	66	68	73	79	83	85	86
September 25	90	90	90	88	84	78	74	71	68	67	66	66	67	72	76	80	83	84

Underlined numbers show times when mean relative humidity values are less than 60%, and hence, are not suitable for aerial herbicide application.

Table 4. Weekly percent probabilities that precipitation will exceed 3 mm for the hours from 0500 to 2200 hours, and for total daily precipitation, based on 20-year (1968-1987) hourly records from the Kapuskasing airport.

Week starting	Time of day (hours)																		Daily total
	0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	
May 01	4	5	5	6	6	7	5	5	7	5	4	3	4	5	3	3	5	2	25
May 08	8	9	8	9	5	5	5	3	3	6	11	10	10	8	9	5	7	8	34
May 15	7	7	8	5	6	5	7	4	4	4	4	6	5	10	9	8	8	8	41
May 22	7	7	2	6	3	5	5	7	6	7	5	6	6	7	7	4	7	4	29
May 29	6	8	6	5	7	5	6	7	9	9	9	8	6	7	9	7	10	7	45
June 05	8	11	9	7	10	11	11	6	6	11	14	11	11	13	11	8	11	10	47
June 12	6	12	11	9	8	9	7	10	12	12	15	19	14	10	7	9	6	11	49
June 19	4	6	4	5	6	7	6	9	7	9	6	5	5	4	9	8	7	7	34
June 26	8	8	4	5	6	5	5	7	8	7	5	7	6	7	11	12	7	6	41
July 03	8	8	2	3	2	2	5	2	2	7	8	9	10	11	10	8	11	11	38
July 10	4	7	5	4	6	4	3	2	3	3	3	6	10	10	6	5	6	8	33
July 17	6	4	3	7	5	7	6	10	6	9	9	9	9	9	5	9	10	10	43
July 24	8	8	7	5	5	7	6	8	7	7	10	12	8	10	7	8	11	8	47
July 31	2	4	6	5	6	6	6	8	8	5	10	7	7	10	9	10	7	5	46
August 07	4	6	6	9	11	7	10	6	4	6	8	10	7	9	7	10	7	7	49
August 14	3	4	7	6	5	5	4	9	7	4	4	7	7	4	5	6	4	2	39
August 21	10	9	6	6	4	5	4	4	5	4	6	5	9	10	9	13	6	6	45
August 28	9	10	12	9	9	5	6	6	4	4	4	8	10	9	10	7	6	5	46
September 04	10	12	12	13	10	10	11	10	13	14	12	16	12	14	10	10	10	11	56
September 11	7	8	8	6	8	5	8	10	8	9	6	13	11	11	6	6	8	8	54
September 18	13	12	10	11	11	10	11	9	12	11	12	10	11	14	12	13	10	5	54
September 25	7	11	7	8	10	10	13	11	11	9	9	10	12	13	13	9	9	6	55

Table 5. Weekly mean wind-speed values (km/hr) for Kapuskasing, for the hours 0500 to 2200, and associated standard deviation values.

		Time of day (hours)																	
Attribute[a]	Week starting	0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200
Mean	May 1	12	12	13	15	16	18	18	19	19	20	20	20	19	18	15	13	12	12
SD		7	7	8	8	8	8	8	9	9	9	8	9	8	8	7	7	6	7
Mean	May 8	12	12	13	15	16	16	17	18	19	19	18	18	18	17	16	14	12	12
SD		7	7	7	7	8	8	8	9	8	8	8	8	8	8	7	7	7	7
Mean	May 15	11	12	13	14	15	17	17	18	19	19	19	18	18	17	16	13	12	12
SD		7	7	7	8	7	8	8	8	8	8	8	8	8	8	7	7	7	7
Mean	May 22	10	11	12	14	14	16	16	17	17	18	17	18	17	16	15	12	11	11
SD		8	8	8	8	9	9	9	9	9	9	9	8	8	8	8	7	7	7
Mean	May 29	10	10	12	13	15	15	16	17	18	18	17	17	17	15	13	11	11	11
SD		6	7	7	7	7	7	8	8	8	8	8	8	8	8	7	7	6	6
Mean	June 5	11	11	13	14	15	16	17	18	18	17	18	17	16	16	15	12	11	12
SD		7	7	7	7	7	8	8	9	9	9	9	8	9	8	8	7	7	7
Mean	June 12	10	10	12	13	14	15	16	17	17	17	17	17	17	15	14	11	10	11
SD		7	8	8	8	8	8	8	9	9	9	10	10	9	8	8	7	7	8
Mean	June 19	9	11	12	13	14	16	16	17	18	18	17	17	16	15	13	11	10	10
SD		6	7	7	8	8	8	8	8	8	8	8	8	8	8	8	7	7	7
Mean	June 26	10	11	12	13	14	15	16	17	17	18	17	16	16	15	13	11	11	11
SD		7	8	7	8	8	8	8	8	8	8	9	9	9	9	8	8	7	7
Mean	July 3	10	10	11	13	14	15	16	17	17	18	17	17	16	14	13	10	10	10
SD		7	7	7	7	7	7	7	8	8	9	9	9	8	8	8	7	7	7
Mean	July 10	9	9	11	12	13	14	15	16	16	16	16	15	14	13	12	10	9	9
SD		7	6	6	7	7	7	8	8	7	7	9	8	8	8	7	7	6	6
Mean	July 17	9	9	10	11	12	13	14	15	15	16	16	16	15	14	11	9	9	9
SD		7	7	7	7	7	7	8	8	8	8	8	8	8	7	6	6	6	6
Mean	July 24	9	10	11	12	13	15	16	16	17	17	17	16	15	13	12	10	10	10
SD		6	6	7	7	7	8	8	8	8	8	8	8	8	7	7	7	7	6
Mean	July 31	9	9	10	11	12	14	15	15	16	16	15	15	14	12	10	9	9	9
SD		6	6	7	6	7	7	7	7	7	7	8	8	8	7	7	7	7	7

(cont'd)

Table 5. Weekly mean wind-speed values (km/hr) for Kapuskasing, for the hours 0500 to 2200, and associated standard deviation values (concl.).

Attribute[a]	Week starting	Time of day (hours)																	
		0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200
Mean	August 7	10	10	10	12	13	15	15	16	16	16	16	16	14	13	12	10	10	10
SD		7	7	7	7	8	8	8	8	8	8	8	8	8	8	7	7	7	7
Mean	August 14	11	10	11	13	14	15	16	17	17	17	17	16	15	13	11	10	9	10
SD		6	6	6	7	7	8	8	8	8	8	8	8	7	7	7	7	7	7
Mean	August 21	10	10	10	12	13	14	15	16	16	16	16	15	14	12	10	10	10	10
SD		7	7	7	7	8	8	8	8	8	8	8	8	8	7	7	7	7	7
Mean	August 28	10	10	11	13	14	15	16	17	17	17	16	16	14	12	10	10	10	11
SD		7	7	8	7	8	8	8	8	9	8	8	9	8	7	7	8	7	7
Mean	September 4	11	11	12	14	15	16	17	18	18	18	18	17	16	13	12	12	12	11
SD		8	7	7	8	8	8	8	8	8	8	8	9	8	7	7	8	8	8
Mean	September 11	10	10	11	13	14	16	16	17	17	17	18	17	15	13	10	10	10	10
SD		7	7	7	7	8	8	8	8	8	8	8	8	8	7	6	7	7	7
Mean	September 18	11	11	12	13	15	16	17	18	18	19	18	18	15	13	11	12	12	12
SD		7	7	7	8	8	8	8	9	9	9	9	8	8	7	7	7	7	7
Mean	September 25	12	12	13	13	14	16	17	18	18	18	18	17	15	13	12	12	12	12
SD		8	8	8	8	8	9	9	9	9	9	9	8	8	8	8	8	8	8

[a]SD = standard deviation

Table 6. Weekly mean ambient air-temperature values (°C) for Kapuskasing, for the hours 0500 to 2200, and associated standard deviation values.

Attribute[a]	Week starting	Time of day (hours)																	
		0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200
Mean	May 1	0.1	0.4	1.4	3.4	4.9	6.3	7.4	8.3	9.1	9.9	10.3	10.4	10.2	9.7	9.0	7.2	5.7	4.5
SD		5.1	5.1	4.9	5.6	5.9	6.3	6.6	6.9	7.0	7.0	7.1	7.1	7.0	6.8	6.6	6.0	5.6	5.5
Mean	May 8	1.7	2.1	3.1	5.0	6.4	7.6	8.7	9.6	10.3	11.0	11.4	11.5	11.3	10.8	10.1	8.5	7.1	6.1
SD		5.2	5.0	4.9	5.4	5.9	6.2	6.4	6.6	6.8	6.9	6.8	6.9	6.8	6.6	6.4	5.8	5.4	5.3
Mean	May 15	4.0	4.5	5.7	7.6	9.1	10.5	11.6	12.6	13.4	14.1	14.4	14.5	14.3	13.8	13.1	11.3	9.7	8.5
SD		5.7	5.5	5.6	6.0	6.5	6.9	7.2	7.4	7.4	7.5	7.5	7.4	7.4	7.4	7.2	6.7	6.3	6.2
Mean	May 22	5.5	6.2	7.5	9.5	11.1	12.4	13.5	14.5	15.1	16.0	16.4	16.5	16.3	15.9	15.3	13.5	11.8	10.5
SD		5.5	5.4	5.5	6.2	6.7	7.1	7.3	7.4	7.5	7.6	7.7	7.8	7.8	7.7	7.4	6.8	6.3	6.1
Mean	May 29	5.9	6.7	8.1	10.0	11.6	12.8	13.9	14.9	15.5	16.0	16.3	16.6	16.5	16.1	15.6	14.1	12.3	10.9
SD		5.0	4.7	4.7	5.2	5.7	6.0	6.3	6.4	6.5	6.6	6.6	6.5	6.4	6.2	6.0	5.6	5.2	5.0
Mean	June 5	7.7	8.4	9.5	11.4	12.9	14.1	15.2	16.1	16.7	17.4	17.6	17.7	17.7	17.2	16.5	14.9	13.2	12.0
SD		5.4	5.3	5.3	5.8	6.3	6.6	6.7	6.8	6.8	6.8	6.7	6.7	6.6	6.5	6.3	5.7	5.5	5.4
Mean	June 12	8.8	9.8	11.0	12.9	14.4	15.8	16.9	17.8	18.3	19.0	19.2	19.4	19.3	18.9	18.3	16.7	14.7	13.5
SD		5.5	5.1	4.8	4.9	5.3	5.6	5.8	6.0	5.9	6.1	6.2	6.3	6.2	6.1	5.9	5.4	5.1	5.0
Mean	June 19	9.4	10.3	11.6	13.5	15.0	16.4	17.5	18.3	19.0	19.6	19.8	19.9	19.8	19.4	18.7	17.1	15.2	13.8
SD		4.9	4.6	4.5	4.7	5.0	5.2	5.5	5.5	5.7	5.9	5.9	5.8	5.7	5.6	5.4	5.0	4.8	4.9
Mean	June 26	11.4	12.2	13.4	15.1	16.6	17.9	19.0	19.9	20.5	21.4	21.7	21.8	21.4	20.8	20.2	18.3	16.5	15.3
SD		4.6	4.2	4.0	4.1	4.4	4.8	5.0	5.2	5.1	5.1	5.1	5.1	5.1	5.1	5.0	4.5	4.3	4.3
Mean	July 3	11.1	11.9	13.1	15.2	16.9	18.2	19.3	20.2	20.6	21.2	21.4	21.5	21.4	20.9	20.2	18.5	16.6	15.4
SD		4.8	4.5	4.2	4.2	4.6	4.8	5.1	5.2	5.3	5.4	5.3	5.3	5.4	5.3	5.1	4.6	4.5	4.6
Mean	July 10	11.6	12.3	13.6	15.6	17.2	18.6	19.7	20.6	21.3	21.9	22.2	22.2	22.1	21.5	20.8	19.0	17.2	16.0
SD		4.5	4.2	3.9	3.9	4.1	4.4	4.6	4.7	4.7	4.8	4.9	4.8	4.8	4.7	4.5	4.1	4.1	4.2
Mean	July 17	12.3	12.9	14.3	16.3	17.9	19.2	20.2	21.0	21.5	22.1	22.6	22.6	22.4	21.9	21.2	19.2	17.4	16.3
SD		4.5	4.2	3.8	3.7	4.0	4.3	4.5	4.6	4.6	4.7	4.7	4.7	4.6	4.5	4.3	3.9	3.9	4.0
Mean	July 24	12.0	12.5	13.5	15.4	17.0	18.3	19.4	20.3	20.9	21.5	21.8	21.8	21.5	21.1	20.3	18.4	16.8	15.7
SD		4.2	4.0	3.7	3.7	4.0	4.4	4.7	4.9	4.9	4.9	4.9	4.9	4.7	4.7	4.4	4.1	4.1	4.1
Mean	July 31	11.1	11.5	12.7	14.8	16.6	18.1	19.3	20.2	20.6	21.2	21.4	21.5	21.3	20.8	20.0	17.7	16.1	15.1
SD		4.2	4.0	3.7	3.5	3.7	4.1	4.3	4.5	4.6	4.5	4.4	4.5	4.4	4.2	4.0	3.6	3.8	3.9

(cont'd)

Table 6. Weekly mean ambient air-temperature values (°C) for Kapuskasing, for the hours 0500 to 2200, and associated standard deviation values (concl.).

		Time of day (hours)																	
Attribute[a]	Week starting	0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200
Mean	August 7	11.0	11.1	12.0	14.1	15.7	17.1	18.2	19.1	19.7	20.4	20.6	20.6	20.4	19.7	18.9	16.7	15.3	14.5
SD		4.3	4.2	3.9	3.9	4.1	4.4	4.7	4.9	5.0	5.1	5.1	5.1	5.0	4.9	4.7	4.2	4.1	4.1
Mean	August 14	10.9	10.9	11.7	13.5	15.3	16.9	18.1	19.0	19.6	20.2	20.5	20.5	20.2	19.6	18.6	16.3	15.0	14.1
SD		4.6	4.6	4.3	4.0	4.1	4.4	4.7	4.9	4.9	5.1	5.2	5.2	5.2	5.0	4.7	4.4	4.4	4.4
Mean	August 21	10.0	9.9	10.5	12.5	14.2	15.9	17.1	18.1	18.7	19.3	19.5	19.4	19.1	18.3	17.2	14.9	13.9	13.2
SD		4.9	4.9	4.6	4.1	4.1	4.3	4.5	4.7	4.8	4.9	4.8	4.8	4.8	4.6	4.3	4.1	4.2	4.4
Mean	August 28	10.1	9.9	10.4	12.2	13.9	15.5	16.6	17.6	18.3	19.0	19.2	19.1	18.8	17.9	16.6	14.7	13.7	13.0
SD		5.4	5.4	5.2	4.8	4.8	5.1	5.3	5.4	5.4	5.4	5.4	5.2	5.2	4.9	4.6	4.5	4.7	4.7
Mean	September 4	8.9	8.7	9.0	10.5	11.9	13.2	14.2	15.0	15.4	16.1	16.3	16.2	15.9	15.1	13.9	12.3	11.6	11.0
SD		5.2	5.2	5.1	4.6	4.5	4.7	4.9	5.0	5.1	5.2	5.2	5.2	5.0	4.8	4.6	4.5	4.6	4.7
Mean	September 11	5.8	5.6	5.8	7.1	8.6	10.0	11.1	12.0	12.6	13.1	13.5	13.4	13.0	12.0	10.6	9.4	8.6	8.1
SD		4.8	4.9	4.8	4.4	4.3	4.6	4.9	5.1	5.3	5.4	5.5	5.5	5.5	5.1	4.7	4.6	4.7	4.8
Mean	September 18	6.2	6.0	6.1	7.2	8.4	9.6	10.7	11.6	12.2	12.7	12.8	12.8	12.3	11.3	10.1	8.9	8.3	7.8
SD		5.2	5.1	5.0	4.7	4.7	4.9	5.2	5.4	5.4	5.6	5.6	5.5	5.4	5.1	5.0	5.0	5.0	5.0
Mean	September 25	4.5	4.4	4.3	5.3	6.5	7.7	8.7	9.5	10.0	10.5	10.7	10.7	10.3	9.3	8.2	7.2	6.6	6.2
SD		4.8	4.8	4.7	4.4	4.3	4.4	4.7	4.8	5.1	5.2	5.2	5.2	4.9	4.7	4.5	4.5	4.6	4.7

[a]SD = standard deviation

Table 7. Weekly mean relative humidity values (%) for Kapuskasing, for the hours 0500 to 2200, and associated standard deviation values.

		Time of day (hours)																	
Attribute[a]	Week starting	0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200
Mean	May 1	79	79	76	69	64	60	56	54	51	49	48	48	48	50	51	57	62	66
SD		14	13	14	17	19	20	21	22	23	23	23	23	23	23	23	21	20	18
Mean	May 8	81	81	78	70	66	63	59	56	54	52	52	51	52	54	56	61	65	69
SD		14	14	15	18	20	22	23	23	23	23	24	24	25	25	25	23	21	20
Mean	May 15	82	81	78	71	65	61	58	55	52	51	50	50	50	52	55	60	65	70
SD		14	14	15	18	20	22	22	22	23	23	23	23	23	24	23	22	20	19
Mean	May 22	83	81	77	69	64	59	56	53	52	49	49	49	49	51	53	58	64	69
SD		13	13	15	18	20	22	23	23	23	23	24	24	24	25	24	23	21	20
Mean	May 29	85	84	79	72	67	63	60	57	54	54	53	52	53	54	56	62	67	72
SD		13	13	15	18	19	20	21	21	22	22	22	22	23	23	23	21	19	18
Mean	June 5	85	84	79	73	67	63	60	57	55	54	54	54	54	55	58	64	70	74
SD		11	11	13	16	18	19	20	20	21	21	22	22	23	22	22	20	18	17
Mean	June 12	87	85	81	74	68	63	60	56	55	53	53	53	53	54	57	63	70	74
SD		11	11	12	15	18	19	20	21	21	22	22	23	23	23	22	20	17	16
Mean	June 19	87	85	81	74	68	64	60	57	55	53	53	52	53	55	58	65	72	76
SD		11	11	12	15	17	18	19	20	20	21	21	20	21	21	21	18	17	16
Mean	June 26	87	85	81	76	71	67	63	60	58	55	54	54	55	57	60	68	75	78
SD		11	11	12	14	16	17	19	19	20	19	19	20	20	21	20	18	15	15
Mean	July 3	88	86	83	76	70	64	61	58	56	55	54	54	55	57	60	67	74	78
SD		10	10	10	12	14	16	17	17	18	19	19	20	20	20	20	17	15	14
Mean	July 10	91	89	85	78	72	66	63	59	57	55	55	55	57	59	62	70	76	80
SD		8	8	9	11	13	14	16	16	16	17	17	17	18	19	18	15	13	13
Mean	July 17	90	89	85	78	72	67	64	61	60	57	56	56	58	60	63	72	78	81
SD		8	8	9	12	14	15	16	17	18	18	18	19	19	19	18	15	13	13
Mean	July 24	90	90	87	81	74	69	64	61	59	57	57	56	58	60	64	72	79	82
SD		8	8	8	11	14	16	16	17	17	17	17	17	17	17	16	13	12	12
Mean	July 31	91	90	87	81	75	68	64	61	59	57	56	56	57	60	64	74	80	82
SD		8	7	8	10	12	15	16	17	17	18	18	18	18	18	16	13	12	12

(cont'd)

Table 7. Weekly mean relative humidity values (%) for Kapuskasing, for the hours 0500 to 2200, and associated standard deviation values (concl.).

		Time of day (hours)																	
Attribute[a]	Week starting	0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200
Mean	August 7	91	91	89	83	77	71	67	63	60	59	58	58	59	63	67	76	80	82
SD		7	7	7	10	12	15	17	17	18	19	19	19	18	18	16	13	13	12
Mean	August 14	90	91	89	83	77	70	65	62	60	58	57	57	59	62	67	77	81	83
SD		8	7	8	10	12	14	15	16	16	16	17	17	17	17	15	13	12	12
Mean	August 21	91	92	90	85	79	72	67	63	60	58	57	58	60	64	71	80	82	84
SD		8	7	7	9	12	14	15	16	16	16	17	18	18	18	15	12	12	11
Mean	August 28	91	91	91	86	80	73	68	64	62	60	59	60	61	65	72	80	83	84
SD		7	6	6	8	11	14	16	17	17	18	18	18	18	17	14	12	11	11
Mean	September 4	91	92	91	87	82	76	72	69	66	64	64	64	65	69	75	81	84	85
SD		7	6	7	9	11	14	15	17	17	18	18	18	18	17	14	12	11	11
Mean	September 11	92	92	92	88	84	77	72	68	65	63	62	62	64	70	76	81	84	85
SD		6	6	6	7	11	13	15	16	17	17	17	18	18	16	13	11	11	10
Mean	September 18	92	92	92	89	84	79	75	71	68	66	66	66	68	73	79	83	85	86
SD		7	7	7	8	10	13	15	16	17	18	19	19	19	17	14	12	12	11
Mean	September 25	90	90	90	88	84	78	74	71	68	67	66	66	67	72	76	80	83	84
SD		8	8	8	8	10	14	15	17	18	19	20	20	20	18	16	14	13	12

[a]SD = standard deviation

Table 8. Weekly mean precipitation values (mm) for Kapuskasing, for the hours 0500 to 2200, and associated standard deviation values.

		Time of day (hours)																	
Attribute[a]	Week starting	0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200
Mean	May 1	0.5	0.3	0.2	0.4	0.8	0.9	0.8	0.5	0.6	0.5	0.3	0.3	0.6	0.7	0.3	0.5	0.7	0.4
SD		2.7	1.5	1.0	1.9	3.4	3.8	4.3	2.6	3.3	2.3	1.7	1.9	3.2	3.7	2.5	3.4	5.2	2.7
Mean	May 8	0.7	0.9	0.6	0.7	0.7	1.0	1.1	0.5	0.4	0.8	1.4	1.6	1.6	1.0	1.2	2.1	0.8	0.7
SD		3.4	4.4	2.7	2.6	3.7	7.7	7.0	4.0	3.6	3.6	5.2	5.5	6.2	4.1	6.6	17.8	5.9	3.1
Mean	May 15	1.0	0.4	0.5	0.4	0.6	0.6	0.7	0.3	0.3	0.4	0.3	0.3	0.8	0.9	1.2	1.3	0.9	0.6
SD		4.7	1.6	2.2	1.9	3.2	2.7	3.1	1.7	1.3	1.8	1.2	1.0	5.7	4.0	6.9	5.7	3.8	2.3
Mean	May 22	0.6	1.0	0.8	0.4	0.1	0.3	0.2	0.7	0.5	0.9	0.9	0.5	0.9	0.8	0.4	0.6	0.4	0.2
SD		2.5	4.7	5.8	2.2	0.9	2.0	1.2	3.3	2.9	4.7	4.5	2.2	4.9	3.7	1.9	3.6	1.4	1.5
Mean	May 29	0.5	0.7	0.7	0.9	1.4	0.8	0.8	0.8	1.9	1.6	1.4	1.1	0.9	0.6	1.2	1.3	0.9	0.6
SD		2.6	3.3	3.9	4.0	6.5	4.7	4.1	4.6	9.2	6.8	5.5	5.2	4.7	2.6	6.0	7.4	3.5	3.2
Mean	June 5	1.1	1.1	0.7	0.6	0.9	1.0	2.5	0.8	1.2	1.2	1.4	1.9	3.7	1.4	1.1	0.8	1.1	1.7
SD		4.9	4.1	2.6	2.8	4.1	3.6	15.0	3.7	5.1	4.7	4.9	8.2	20.1	5.7	4.4	3.1	4.6	7.7
Mean	June 12	1.4	1.1	0.6	0.8	1.4	1.1	1.1	0.7	0.9	1.8	2.0	2.8	1.5	1.3	1.2	1.4	1.4	1.9
SD		7.2	3.8	1.9	3.7	7.7	4.5	5.3	2.5	3.5	6.5	7.6	8.0	5.4	7.5	5.0	7.5	7.2	8.6
Mean	June 19	1.0	0.4	0.7	1.3	0.9	1.1	1.1	1.5	0.8	1.6	1.9	1.9	0.9	1.1	2.4	1.6	0.8	1.1
SD		5.9	1.5	4.5	8.5	4.9	5.7	5.7	7.2	3.7	7.6	11.4	11.9	5.2	5.7	16.5	8.5	3.5	7.3
Mean	June 26	0.8	0.9	1.0	0.9	0.6	0.6	0.8	0.7	0.9	1.0	0.7	0.9	1.3	1.0	2.2	1.8	0.7	0.9
SD		3.6	4.0	7.8	4.7	3.1	3.1	4.0	3.4	4.7	4.3	5.2	4.5	8.8	5.7	9.6	6.7	3.2	6.0
Mean	July 3	2.4	1.3	0.7	0.4	0.2	0.1	0.7	0.1	0.1	1.2	1.4	1.3	3.4	2.6	2.2	1.5	1.1	1.6
SD		11.5	7.1	5.7	3.1	0.9	0.8	5.9	0.8	1.0	5.5	6.7	5.2	15.1	10.0	10.2	6.7	4.1	7.6
Mean	July 10	0.9	0.7	0.6	1.1	0.8	0.9	0.4	0.4	0.5	0.7	0.3	0.7	1.2	1.8	0.8	1.1	1.8	1.2
SD		5.8	3.9	2.6	6.6	4.9	6.5	2.7	4.0	4.3	4.0	2.4	3.0	4.3	8.2	5.4	6.1	10.4	5.4
Mean	July 17	0.5	0.8	1.8	1.2	0.9	1.2	0.8	1.2	3.2	3.0	1.3	2.4	5.9	1.7	2.1	2.1	1.8	4.0
SD		2.8	5.7	14.9	6.8	4.9	6.8	4.1	6.3	21.3	15.7	6.0	10.3	34.1	9.0	15.0	9.7	7.4	27.4
Mean	July 24	0.8	0.6	0.5	0.4	0.7	0.7	0.9	1.1	2.0	1.2	2.5	1.4	1.0	2.7	0.8	1.0	1.6	1.4
SD		3.7	2.6	2.0	2.1	3.6	3.6	5.1	4.9	12.1	5.3	11.3	4.4	5.2	15.6	4.2	4.7	7.4	10.4
Mean	July 31	0.4	1.1	1.1	0.7	1.1	0.9	1.4	1.8	0.6	0.6	1.7	1.5	0.9	2.3	1.4	1.1	1.3	1.1
SD		3.0	6.9	7.5	4.1	6.3	5.5	11.3	7.5	2.9	3.2	8.1	8.2	4.2	16.9	7.3	4.5	6.1	6.1

(cont'd)

Table 8. Weekly mean precipitation values (mm) for Kapuskasing, for the hours 0500 to 2200, and associated standard deviation values (concl.).

		Time of day (hours)																
Attribute[a]	Week starting	0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200
Mean	August 7	0.5	0.6	0.9	0.9	2.2	0.7	1.1	1.9	0.4	0.6	0.6	1.5	1.2	1.6	0.7	2.0	2.1	1.4
SD		2.5	2.4	4.7	3.7	9.8	4.0	5.2	13.8	2.1	3.1	2.8	5.8	5.0	7.1	3.0	8.1	9.5	6.6
Mean	August 14	0.2	0.4	2.8	2.5	1.5	1.2	0.3	0.7	1.3	1.0	0.4	0.6	0.5	0.2	0.4	0.4	0.4	0.4
SD		1.3	2.4	17.2	14.1	9.4	8.2	2.2	2.7	9.4	5.9	1.8	3.2	2.0	0.9	2.4	2.1	2.3	2.6
Mean	August 21	1.1	1.8	0.9	0.6	0.5	0.3	0.2	0.3	0.5	0.3	0.4	0.8	0.7	2.5	2.2	3.7	1.3	0.4
SD		6.3	8.2	4.2	3.3	3.4	1.7	1.3	1.8	3.2	1.6	2.1	4.2	2.7	10.9	10.7	17.1	7.8	1.8
Mean	August 28	1.9	2.4	3.2	1.1	1.6	0.7	1.0	0.7	2.4	1.1	1.2	2.3	1.5	1.7	1.4	1.0	0.4	0.3
SD		9.0	9.2	14.9	4.3	5.8	4.8	4.8	3.3	22.6	6.6	8.0	11.4	6.3	8.0	7.0	6.0	1.5	1.3
Mean	September 4	1.2	1.2	1.3	1.6	0.9	1.4	0.9	1.1	1.8	1.5	1.3	2.1	1.1	1.6	1.0	2.4	1.7	3.0
SD		6.0	4.3	4.7	8.7	3.5	8.0	2.8	4.3	7.0	4.7	4.5	7.6	4.3	5.7	3.7	15.6	8.7	10.8
Mean	September 11	0.5	0.6	0.5	0.5	0.6	0.6	0.6	1.0	0.8	1.2	0.8	1.1	1.2	1.3	1.0	0.7	1.2	0.9
SD		1.9	2.2	2.0	2.1	2.4	3.3	2.2	3.9	4.0	4.8	4.7	3.7	4.0	4.8	6.1	3.5	6.4	4.2
Mean	September 18	2.1	1.6	1.2	1.5	2.5	2.0	1.3	1.2	1.0	0.9	1.2	1.5	1.5	1.7	1.4	1.5	0.8	0.8
SD		9.5	6.8	4.5	5.4	9.6	8.0	5.1	4.8	3.2	3.2	4.2	5.9	6.2	5.2	5.0	5.3	2.9	4.1
Mean	September 25	1.3	1.9	0.9	0.7	0.8	0.9	1.4	1.2	1.3	1.1	1.1	1.3	1.4	1.7	1.6	1.1	0.7	1.2
SD		6.4	10.9	3.7	2.9	2.5	3.8	4.7	4.1	5.2	5.6	6.3	4.7	5.0	6.3	5.9	3.9	3.4	7.8

[a]SD = standard deviation

Table 9. Mean percent probability that wind speed, air temperature, relative humidity and rainfall conditions will be suitable for aerial herbicide application, based on 20-year (1968-1987) hourly records from the Kapuskasing airport.

	Time of day (hours)																	
Week starting	0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200
May 01	4	5	5	5	0	1	0	1	1	0	0	0	2	2	6	8	6	9
May 08	6	5	5	7	5	7	7	6	4	3	6	2	5	4	5	5	9	12
May 15	20	19	16	15	11	8	7	5	3	1	3	1	0	4	3	6	21	24
May 22	38	39	35	21	13	11	7	4	5	4	4	2	2	5	5	8	16	30
May 29	31	32	36	31	17	13	15	8	4	6	2	4	5	11	15	28	34	31
June 05	36	28	26	20	13	9	6	3	7	6	7	6	6	4	9	21	31	33
June 12	50	45	45	34	18	16	13	8	10	9	6	8	5	9	11	23	47	46
June 19	50	51	48	30	17	9	4	3	3	2	4	2	3	3	4	17	46	51
June 26	51	50	45	26	18	10	5	6	6	4	5	6	5	6	7	25	49	56
July 03	51	50	55	32	16	7	5	3	3	2	5	3	1	6	5	24	48	54
July 10	66	52	49	44	24	10	8	6	3	3	3	3	5	5	10	35	58	63
July 17	72	70	69	47	24	17	13	7	12	5	8	8	7	11	16	44	64	71
July 24	68	65	57	56	37	17	10	4	3	4	3	4	4	8	15	50	66	62
July 31	69	71	68	44	29	15	10	8	7	4	5	7	9	12	18	50	65	63
August 07	63	54	54	40	31	17	10	7	8	7	5	4	5	16	20	44	52	62
August 14	51	48	60	37	31	21	8	6	7	5	6	5	4	9	19	57	69	69
August 21	51	48	56	53	50	25	13	7	5	5	4	8	8	9	40	63	64	74
August 28	41	42	39	39	33	24	13	12	7	8	6	6	11	21	46	67	58	52
September 04	28	29	28	31	35	25	12	11	10	6	7	9	11	20	37	53	61	49
September 11	25	25	32	24	33	22	16	14	16	10	8	8	13	23	56	60	48	47
September 18	21	17	20	17	25	23	15	14	8	10	8	7	10	22	42	34	27	30
September 25	10	12	11	21	19	16	10	12	8	4	5	5	10	21	25	27	24	24

Doubly underlined numbers represent times when work probabilities exceed 40%. Singly underlined numbers represent times when work probabilities exceed 10%.

September. The length of time available in the evening window is less than that in the morning window in June and July, but the evening window continues to expand through August and the early part of September. Hence, as the season progresses, the best work chance appears to shift from the morning window in July to the evening window in August and the early part of September. Note that the week of 21 August has unusually high probabilities in relation to the adjacent time periods. Over the course of the season, the highest probabilities occur as follows:

1. from 10 July to 27 August, 0500 to 2200 hours (for the period 0500 to 0800 hours, probabilities range from 41 to 72%, and probabilities for 0900 hours range from 24 to 50%)

2. from 17 July to 20 August, 0800 to 2200 hours (during these times the probabilities range from 44 to 71%)

3. from 21 August to 17 September, 1800 to 2100 hours (during these times the probabilities range from 40 to 74%).

These diurnal and seasonal patterns are illustrated graphically in Figures 2 through 6 for the months from May to September, respectively. Changes in workday probabilities over the season for the morning and the evening windows are illustrated in Figures 7 and 8, respectively.

For operational planning purposes, it is useful to know the total number of potential work hours available over the course of the season for the aerial application of herbicides. For each hour during the day (0500 to 2200 hours), the total number of work hours meeting the aerial application criteria was calculated for the years 1968 to 1987, for the entire field season (1 May to 30 September, Table 10), and for the period during which most aerial herbicide tending is conducted (1 July to 31 August, Table 11). The means, minima and maxima, and 95% confidence intervals about the means are listed at the bottom of each table for the hours 0500 to 2200.

From 0500 to 0900 and from 1800 to 2200, the mean total number of hours available over the long term is 359 hours, or about 36 days over a 5-month period from 1 May to 30 September. Realistically, however, aerial herbicide applications are usually carried out during the 2-month period from mid-July to the end of August. During that period, on average, approximately 18 to 20 total days are available for aerial spraying, or less than one-third of the total number of days potentially available during that period.

Note, however, that there is considerable variation in the actual number of days and hours available from year to year. The mean values listed in Tables 10 and 11 can be used during planning to estimate the probable amount of time available for spraying, but the variability represents the risk involved and should be accounted for by contingency planning. For example, there is a 10% risk that there will be fewer than 14 suitable days available from 1 July to 31 August in any given year. Since 1968, there have been as few as 65 hours (13 days) and as many as 151 hours (30 days) available for spraying during the morning window, and as few as 58 hours (12 days) and as many as 117 hours (23 days) available during the evening window.

Geographic Variability

Paired-sample t-tests were conducted to determine if significant differences were present between air temperature and rainfall at the four fire-weather monitoring stations and the Kapuskasing Experimental Farm. These tests showed significant differences at the 95% confidence level for all attributes and stations except for rainfall at the station located in Opasatika Township (Table 12). However, the paired sample t-test is very sensitive, and the mean differences may not be meaningful in terms of their effect on work probabilities. Hence, work probabilities for the four fire-weather monitoring stations were calculated and compared with the long-term mean values calculated from the information from the

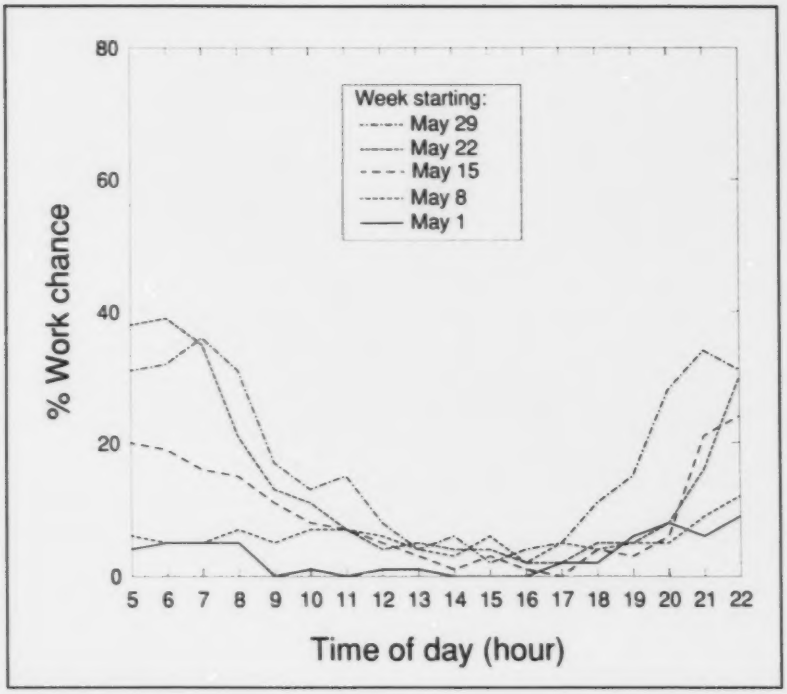

Figure 2. Work chance (%) from 0500 to 2200 hours for the weeks from 1 May to 5 June.

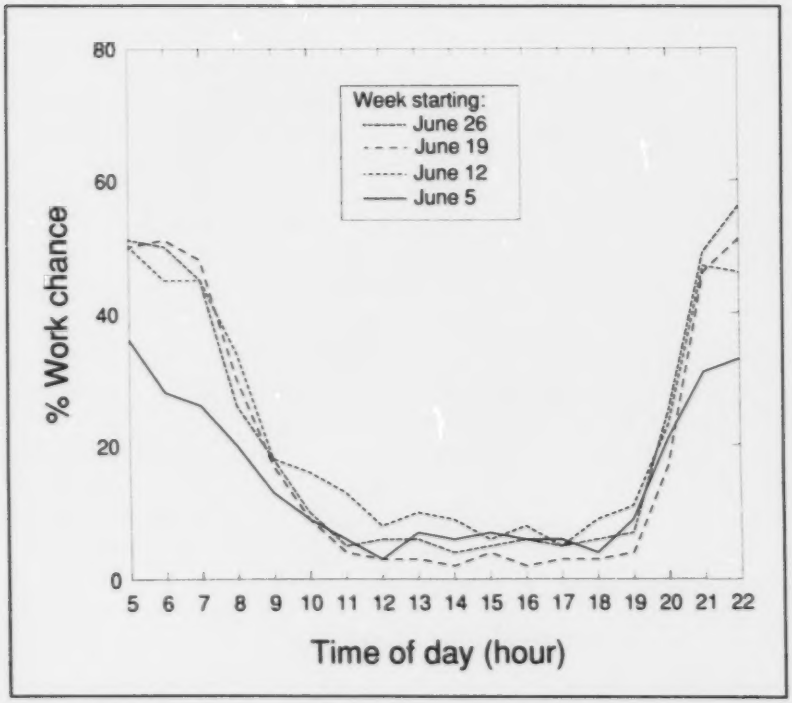

Figure 3. Work chance (%) from 0500 to 2200 hours for the weeks from 5 June to 3 July.

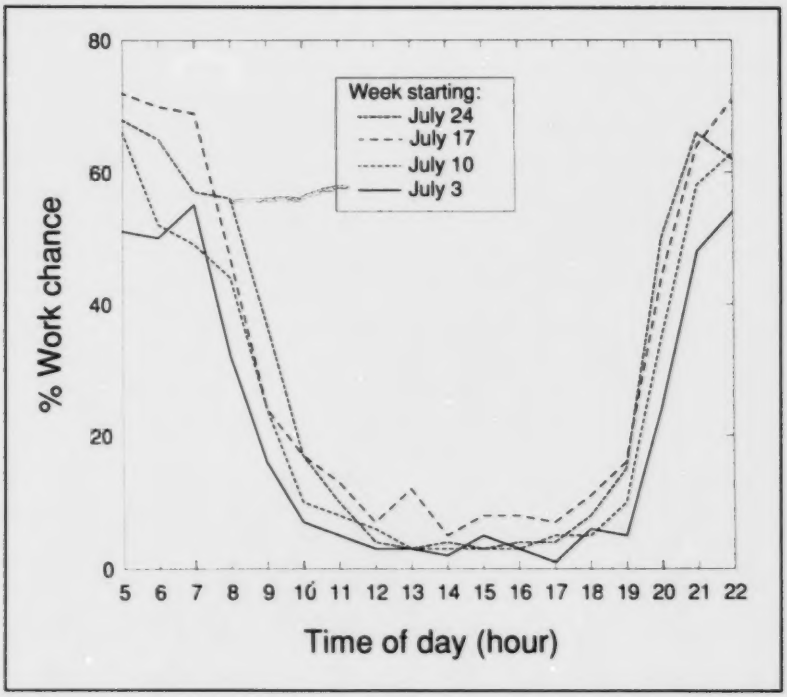

Figure 4. Work chance (%) from 0500 to 2200 hours for the weeks from 3 July to 31 July.

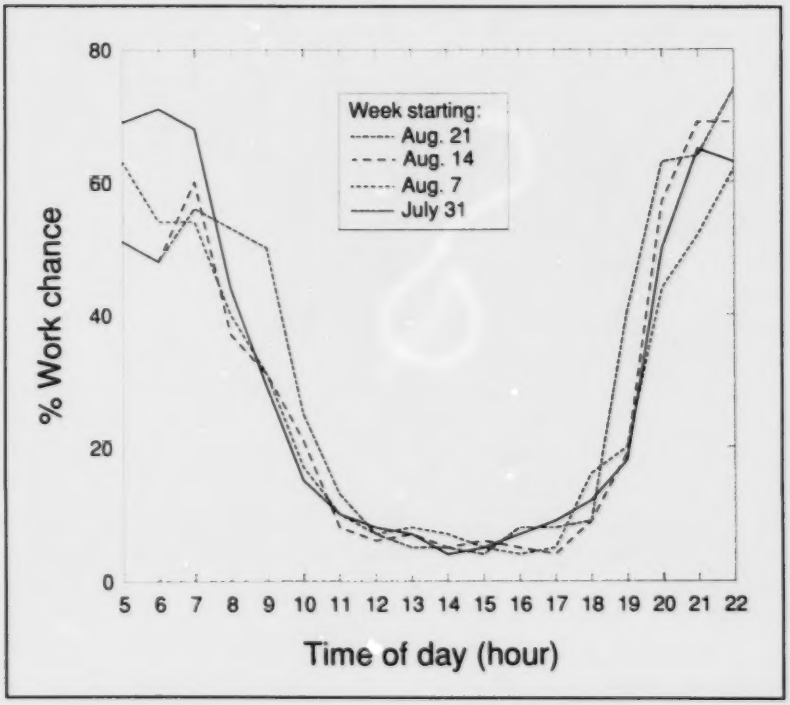

Figure 5. Work chance (%) from 0500 to 2200 hours for the weeks from 31 July to 28 August.

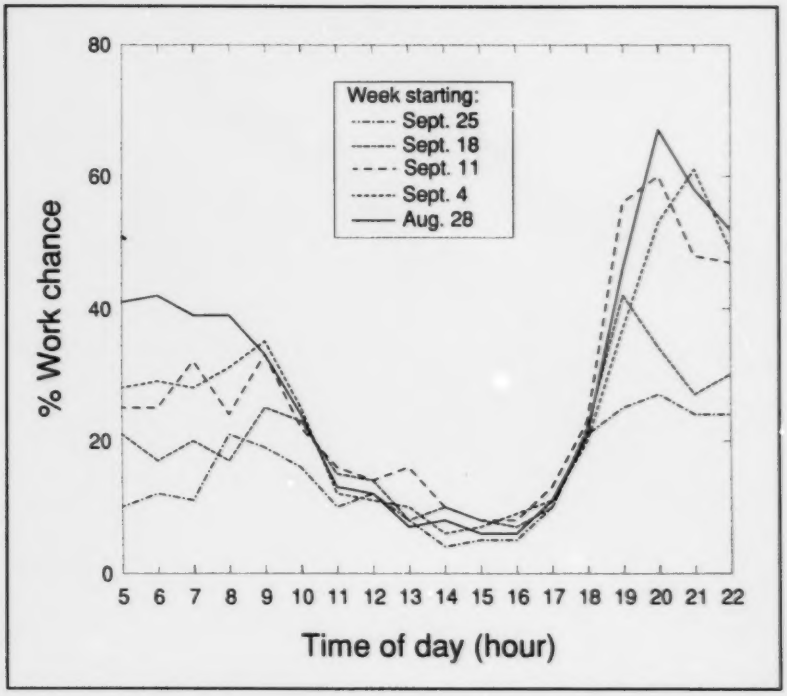

Figure 6. Work chance (%) from 0500 to 2200 hours for the weeks from 28 August to 1 October.

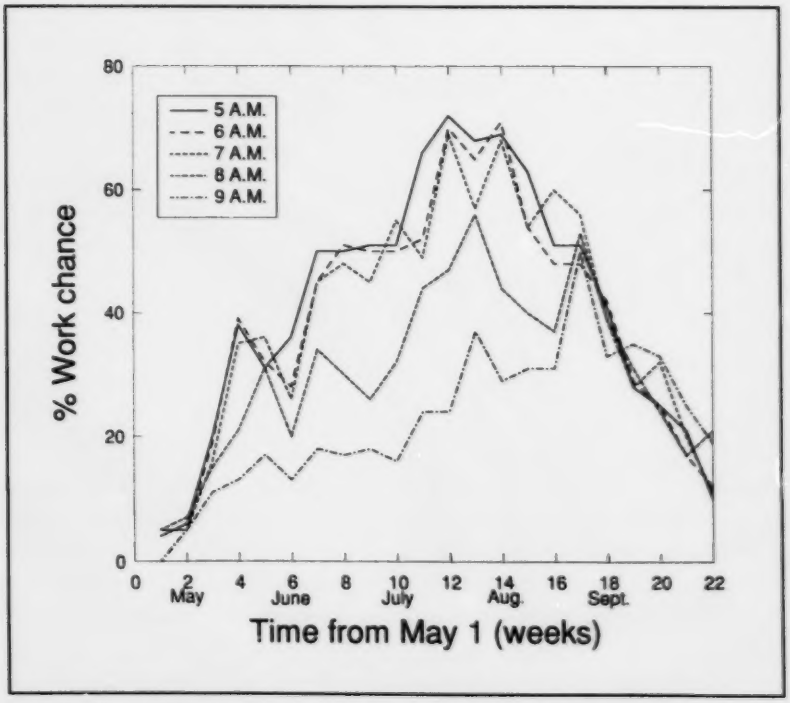

Figure 7. Work chance (%) over the course of the summer (0500 – 0900 hours).

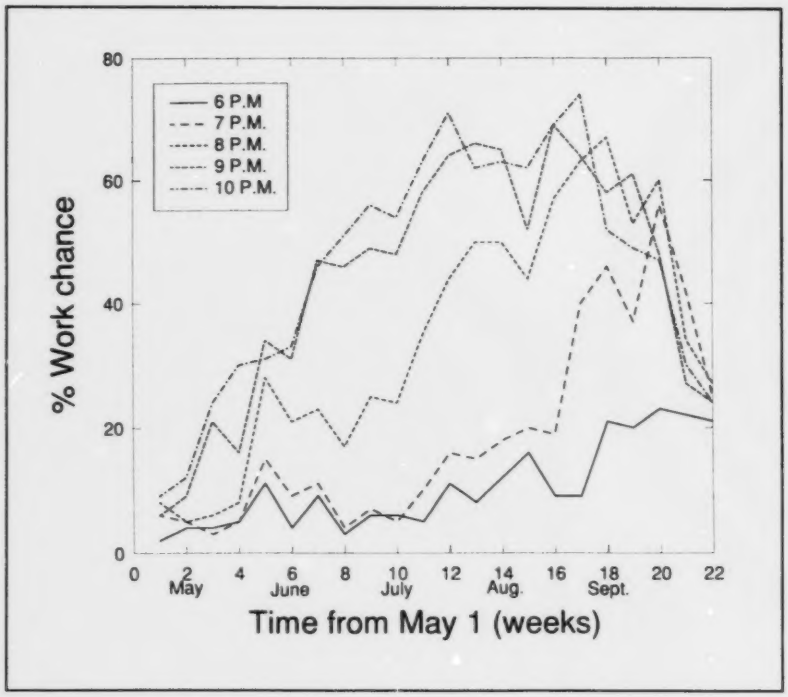

Figure 8. Work chance (%) over the course of the summer (1800 – 2200 hours).

Kapuskasing Airport (Table 13). In general, during the ideal 2,4-D spray windows (from 10 July to 30 July) there are fewer workdays available in Slack and Barker Townships. This is largely related to increased wind speeds in those areas. In general, however, the differences are small, and may not be predictable over the long term. More data are required from these stations to estimate geographic variability accurately.

CONCLUSIONS

Operational planning is concerned with determining in advance when and how to conduct aerial herbicide operations for optimum effect, and the material and manpower requirements to achieve these objectives. Hence, it is useful for the manager to be able to predict the availability of suitable weather conditions for aerial applications over the course of the field season.

Historical weather records can be used to determine whether climatic parameters meet certain criteria within specific periods of time. This, in turn, can be used to estimate work probabilities for forestry tending operations. Historical estimates can also be used to predict the total amount of suitable time, and the percentage of suitable time for a future operation. The year-to-year variation in the occurrence of suitable climatic conditions determines confidence intervals about these estimates. Conversely, mean risk can be predicted from the historical records by estimating the chance that unsuitable conditions will occur. Periods of time where the work chance has been the greatest can be identified over the course of the field season and over the course of the day by summarizing the historical records on a weekly and hourly basis.

In this report, a method for determining work probabilities was illustrated for the Kapuskasing area. The technique could be applied to other

Table 10. Total annual work hours suitable for aerial herbicide application, from 1 May to 30 September, for the years 1968 to 1987.

Year	Time of day (hours)																	
	0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200
1968	41	40	41	42	31	19	10	9	8	5	4	10	8	13	24	45	54	53
1969	29	25	32	24	21	15	7	2	8	7	4	3	6	15	21	36	37	35
1970	33	39	39	28	15	14	8	5	3	5	5	6	5	15	20	34	34	38
1971	42	42	41	38	31	20	14	11	7	7	9	7	9	15	24	43	47	54
1972	33	32	34	29	24	21	11	5	3	6	4	5	10	15	23	40	44	44
1973	39	39	39	31	19	11	10	7	5	3	6	3	2	8	11	26	37	45
1974	34	37	44	34	24	16	10	8	8	7	6	8	7	8	21	32	46	48
1975	51	52	47	38	25	19	12	10	10	6	9	4	4	6	14	40	51	61
1976	41	36	45	24	20	14	6	4	4	2	4	3	6	7	10	30	31	37
1977	39	41	39	30	26	15	10	7	7	7	7	4	5	10	18	33	46	51
1978	32	32	35	29	20	17	13	12	6	5	7	5	8	12	18	31	42	39
1979	53	48	47	38	31	12	10	7	8	5	6	10	7	15	28	41	48	55
1980	52	53	44	27	24	16	13	8	7	2	2	2	3	8	15	36	54	58
1981	61	57	53	42	26	12	7	4	5	5	5	8	7	8	19	39	59	58
1982	55	53	52	39	31	20	15	14	11	7	7	6	9	16	30	47	60	69
1983	62	47	42	32	24	20	14	14	10	9	7	6	5	10	22	35	52	54
1984	43	40	37	31	18	13	6	6	8	5	4	5	5	17	27	47	52	48
1985	61	52	52	43	31	21	10	8	6	2	4	6	7	8	24	46	51	55
1986	40	38	47	34	26	17	12	11	11	9	6	2	8	13	28	35	62	51
1987	61	54	49	41	32	11	9	3	5	4	4	5	10	12	17	33	56	59

(cont'd)

Table 10. Total annual work hours suitable for aerial herbicide application, from 1 May to 30 September, for the years 1968 to 1987 (concl.).

Year	Time of day (hours)																	
	0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200
	Total number of suitable work hours																	
Minimum observed	29	25	32	24	15	11	6	2	3	2	2	2	2	6	10	26	31	35
Maximum observed	62	57	53	43	32	21	15	14	11	9	9	10	10	17	30	47	62	69
Mean total hours	45	43	43	34	25	16	10	8	7	5	6	5	7	12	21	37	48	51
95% confidence interval (±)	5	4	3	3	2	2	1	2	1	1	1	1	1	2	3	3	4	4
	Percent of total time available																	
Minimum (%)	19	16	21	16	10	7	4	1	2	1	1	1	1	4	7	17	20	23
Maximum (%)	41	37	35	28	21	14	10	9	7	6	6	7	7	11	20	31	41	45
Mean (%)	29	28	28	22	16	11	7	5	5	4	4	4	4	8	14	24	31	33

Table 11. Total annual work hours suitable for aerial herbicide application, from 1 July to 31 August, for the years 1968 to 1987.

Year	Time of day (hours)																	
	0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200
1968	19	18	22	16	11	9	2	2	2	1	0	4	2	4	12	23	27	27
1969	18	18	21	13	8	7	3	0	3	4	1	2	1	4	7	17	23	21
1970	20	21	21	20	6	8	6	3	3	2	2	4	1	6	10	18	18	20
1971	14	16	17	13	14	6	5	2	2	2	2	1	2	6	12	27	25	25
1972	22	21	23	18	15	15	7	2	1	3	1	4	7	9	13	28	30	34
1973	32	31	31	21	12	3	5	2	3	0	2	2	2	3	4	17	29	33
1974	21	24	28	17	13	8	4	3	2	2	0	4	4	3	10	18	25	27
1975	24	25	24	17	10	6	7	4	4	3	5	2	2	1	4	18	26	32
1976	23	20	27	15	9	5	2	1	0	1	2	1	1	1	3	16	17	21
1977	19	18	15	12	10	4	0	2	2	3	1	0	1	3	6	18	20	21
1978	14	13	19	13	6	2	2	1	0	0	2	2	3	4	7	12	19	20
1979	32	29	31	23	20	5	3	2	4	3	4	5	4	8	9	22	28	29
1980	36	35	30	21	17	9	7	5	4	0	2	1	3	6	10	22	31	35
1981	38	35	33	26	16	4	1	0	0	0	1	1	2	2	6	19	36	36
1982	29	27	26	22	20	9	9	7	6	3	5	4	4	8	15	27	34	33
1983	40	33	29	20	13	10	7	7	5	3	2	0	1	0	2	17	26	30
1984	32	27	22	22	14	9	4	2	3	1	1	1	1	7	11	30	30	28
1985	38	33	31	28	21	13	8	5	4	2	3	3	2	4	11	30	31	34
1986	25	25	30	24	16	7	3	3	3	3	3	0	2	3	10	18	31	27
1987	35	28	23	21	16	2	2	2	1	1	2	3	3	4	7	16	28	31

(cont'd)

Table 11. Total annual work hours suitable for aerial herbicide application, from 1 July to 31 August, for the years 1968 to 1987 (concl.).

Year	Time of day (hours)																	
	0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200
	Total number of suitable work hours																	
Minimum observed	14	13	15	12	6	2	0	0	0	0	0	0	1	0	2	12	17	20
Maximum observed	40	35	33	28	21	15	9	7	6	4	5	5	7	9	15	30	36	36
Mean total hours	27	25	25	19	13	7	4	3	3	2	2	2	2	4	8	21	27	28
95% confidence interval (±)	4	3	2	2	2	2	1	1	1	1	1	1	1	1	2	2	2	2
	Percent of total time available																	
Minimum (%)	23	21	24	19	10	3	0	0	0	0	0	0	2	0	3	19	27	32
Maximum (%)	65	56	53	45	34	24	15	11	10	6	8	8	11	15	24	48	58	58
Mean (%)	43	40	41	31	22	11	7	4	4	3	3	4	4	7	14	33	43	45

Table 12. Results of paired-sample t-tests for 1988 data from fire-weather monitoring stations versus data from the Environment Canada station at the Kapuskasing Experimental Farm.

Station	Climatic element	Mean difference	SD difference	T value	Probability
Opasatika	Maximum air temperature	-2.8	2.1	12.0	<0.001
Harmon		-3.6	3.3	8.8	<0.001
Slack		-2.4	3.2	6.7	<0.001
Barker		-1.9	2.0	8.7	<0.001
Opasatika	Total daily rainfall	-3.1	16.2	1.7	0.087
Harmon		-10.5	7.0	12.4	<0.001
Slack		3.6	15.4	2.1	0.038
Barker		9.7	13.5	6.5	<0.001

areas by using historical climatic records from weather monitoring stations across Ontario. In recent years, these records have become available in microcomputer format from the Atmospheric Environment Service of Environment Canada, making it possible for local managers to conduct their own analyses.

The amount of time available that will be suitable for aerial spraying is not the only consideration in planning the timing of herbicide application programs. An applicator must be able to make reasonably accurate predictions of the efficacy of a herbicide treatment before an operational program is feasible (Anon. 1985b). Efficacy is determined by many factors, including the characteristics of the herbicide (mode of action, solubility, persistence, selectivity); application methods (application rate, carrier, volume delivered, frequency of applications, timing of application in relation to climate and phenology); and the nature of the target (susceptibility, age-specific susceptibility, density and degree of establishment, level of control desired, and the relationship between crop and target) (McCormack 1980).

Ideally, herbicide applications should be timed so as to maximize effects on target species and to minimize effects on crop species. This requires knowledge of the effects of the herbicide being used, in relation to phenology of the plant species being treated (Anon. 1985c). This report deals only with the availability of those times with climatic conditions suitable for aerial applications, but does not take into account timing of the application in relation to the phenology of the target and crop species. Hence, although climatic conditions suitable for spraying may be available during a given time period, the phenological development stages of the target or crop species at that time may not be suitable for herbicide application, and vice versa.

For example, interest has been expressed by local industry in Kapuskasing in conducting release applications of 2,4-D for control of alder (*Alnus* spp.) in late May and early June, after the alder has flushed but while the black spruce crop trees are still dormant (Anon. 1985c), but this has proven impractical due to the lack of weather conditions suitable for aerial applications and the inability to make accurate predictions of phenological development early in the season because of high inherent variability.

Table 13. Comparison of weekly 0800 hours aerial herbicide application probabilities and total suitable work hours, calculated from 1988 fire-weather monitoring station data, with long-term mean values.

	Weekly 0800 probability, 1988				
Week of	Opasatika	Harmon	Slack	Barker	30-year mean
May 11-May 21	40	0	30	20	15
May 22-May 28	43	0	43	43	21
May 29-June 04	71	57	43	71	31
June 05-June 10	43	0	57	57	20
June 11-June 18	43	57	14	43	34
June 19-June 25	43	43	29	43	30
June 26-July 02	43	29	43	29	26
July 03-July 09	57	57	29	29	32
July 10-July 16	71	57	57	43	44
July 17-July 23	71	57	57	86	47
July 24-July 30	43	57	57	43	56

	Cumulative workdays, 1988 (based on 0800 hours)				
Week of	Opasatika	Harmon	Slack	Barker	30-year mean
May 11-May 21	4	0	3	2	1
May 22-May 28	7	0	6	5	3
May 29-June 04	12	4	9	10	5
June 05-June 10	15	4	13	14	6
June 11-June 18	18	8	14	17	8
June 19-June 25	21	11	16	20	11
June 26-July 02	24	13	19	22	12
July 03-July 09	28	17	21	24	15
July 10-July 16	33	21	25	27	18
July 17-July 23	38	25	29	33	21
July 24-July 30	41	29	33	36	25

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